A New Polarization-Reconfigurable Antenna for 5G Wireless Communications

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Abstract. This paper presents a circular polarization reconfigurable antenna for 5G applications, which is compact in size and has good axial ratio and frequency response. The proposed microstrip antenna is designed on a FR-4 substrate with a relative dielectric constant of 4.3 and has a maximum size of 30×30 mm^2 with 50 Ω coaxial probe feeding. This design has two PIN diode switches controlling reconfiguration between right hand circular polarization (RHCP) and left hand circular polarization (LHCP). To achieve reconfigurability, a C-slot rectangular patch antenna with truncated corner techniques is employed by cutting off two corners on the radiating patch. The proposed antenna has been simulated using CST microwave studio software: it has 3.35–3.77 GHz and 3.4–3.72 GHz bands for both states of reconfiguration, and each is suitable for 5G applications with a good axial ratio of less than 1.8 dB and good gain of 4.8 dB for both modes of operation.

Keywords: Microstrip antennas · Reconfigurable · 5G · Circular polarization

1 Introduction

Many recent books and articles have discussed the use of reconfigurable antennas for "green" flexible RF in 5G applications [1–3]. This topic is of increasing interest for industry because of the requirement for antennas which offer additional functionality and have flexible properties, with the same or smaller physical sizes than previously [4–6]. The 3.4–3.8 GHz frequency band has been identified as a good candidate for 5G applications because of the availability of spectrum [7].

Polarization reconfigurable antennas can help to provide protection from interfering signals in variable environments, offering an additional degree of freedom to increase link quality in the form of altered antenna diversity. In addition, they can be used in active read, write tracking and tagging applications and to enhance channel capacity [8]. Several antennas have been developed to deliver reconfigurable polarization characteristics using switches. Su et al. proposed and fabricated polarization reconfigurable circular-polarized antenna for GPS systems using four photoconductive diodes [9]: by controlling the switching state for each of four diode switches on a

microstrip antenna, the radiation polarization can be altered from linear to circular, either left hand or right hand circular polarization (LHCP or RHCP). Khidre et al. [10] designed a single-aperture-fed dual-band reconfigurable antenna for polarization diversity for WLAN applications. The antenna operates at both 2.4 and 5.8 GHz bandwidth using four shorting posts. The impedance bandwidths for the two bands were 3.6% and 4.3%, respectively, and each band radiates horizontal, vertical and linear polarization, controlled by PIN diode switches. Constant radiation patterns are achieved for different states of polarization with a maximum cross-polarization of −13 dB and −9 dB for the two bands, respectively. Boonying et al. proposed a polarization reconfigurable antenna for WLAN applications at 2.4–2.484 GHz controlled by six PIN diode switches [11]. Other researchers have also presented designs for 5G applications – for example in [12], an antenna is designed with circular polarization reconfigurability between LHCP and RHCP, applicable in mobile systems.

In this paper, the diversity of a polarization-reconfigurable microstrip antenna with semicircle slot is investigated, based on an antenna with two PIN diode switches giving rise to orthogonal RHCP and LHCP. The orthogonality should occur at least in the direction normal to the antenna, since it is hard to achieve orthogonal polarizations over the whole sphere.

2   Antenna Design

In the proposed design, the radiator is fed by a 50 Ω standard probe. An FR-4 substrate is used with h = 3.2 mm, ε_r = 4.3 and loss tangent = 0.02. The frequency 3.6 GHz is chosen as the resonance frequency because this frequency is suitable for 5G. A coaxial probe type feed is used. The center of the patch is taken as the origin and the feed point location is given by the co-ordinates (x_f, y_f) from the origin. The location of the feed point is found using CST software, whose parametric optimizer identifies where the input impedance is 50 Ω at the resonant frequency. At 3.6 GHz, the optimized feed point location is (x_f = 14.3 mm, y_f = 14.6 mm). The antenna is designed with two PIN diodes switches, modeled with a lumped element network which gives 0.9 Ω as the resistance value of a diode in the ON state and 0.3 pF as its capacitance value in the OFF state. The optimized dimensions are achieved by using the built-in optimizer embedded with the CST software. CST time domain solver has been used with 10 lines per wavelength as mesh density control properties. The dimensions of this antenna are optimized to ensure good matching at resonance. The geometry of the antenna and its optimized dimensions are shown in Fig. 1 and Table 1, respectively.

3   Simulation Results

In this section, the polarization diversity antenna is studied in terms of return loss, radiation pattern, gain and polarization. The simulation results are generated using CST software.
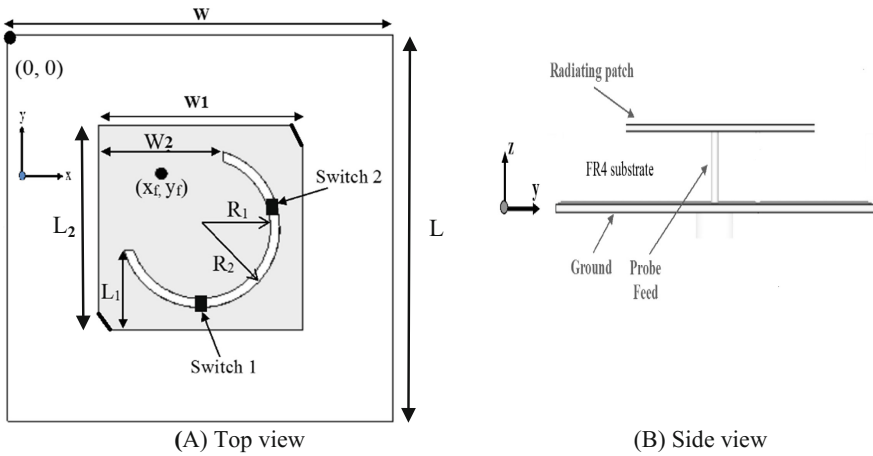
(A) Top view   (B) Side view

Fig. 1. Proposed polarization-reconfigurable microstrip antenna

Table 1. The optimized dimensions of the antenna (Units in mm)

W	L	L_2	W_1	W_2	L_1	R_1	R_2
30	30	17	17	9	8	6	7

3.1 Impedance Bandwidth

The simulation results for the return loss of proposed antenna in Fig. 2 show that, by altering the state of the two PIN diodes, the reflection coefficient |S11| is maintained, which is an advantage of this design. At the resonance frequency, the measured effective bandwidths (S11 < −10 dB) for (D1ON, D2OFF) and (D1OFF, D2ON) are 11% and 8%, respectively, for both states.
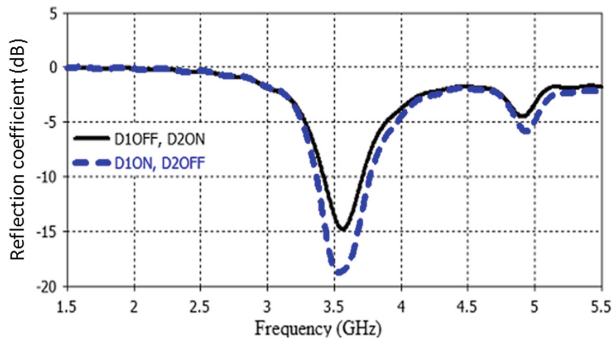

Fig. 2. Return loss for microstrip antenna with two switch modes

3.2   Radiation Pattern, Axial Ratios and Gains

Figure 3 shows the simulated radiation patterns of the antenna in different switch states (in RHCP and LHCP) at resonance frequencies. Full wave simulation is carried out using CST software. The yz-coordinates are taken into account as the E-plane and xz-coordinates as the H-plane. These results are simulated at 3.6 GHz. It is shown that the main lobe direction for (D1On, D2Off of the xz-plane) and (D1Off, D2On of the yz-plane) are on the $\Phi = 0$ and $\theta = 0$, whereas the main lobe direction for (D1On, D2Off of the yz-plane) and (D1Off, D2On of the xz-plane) are on the $\Phi = 10$ and $\theta = -10$, respectively.
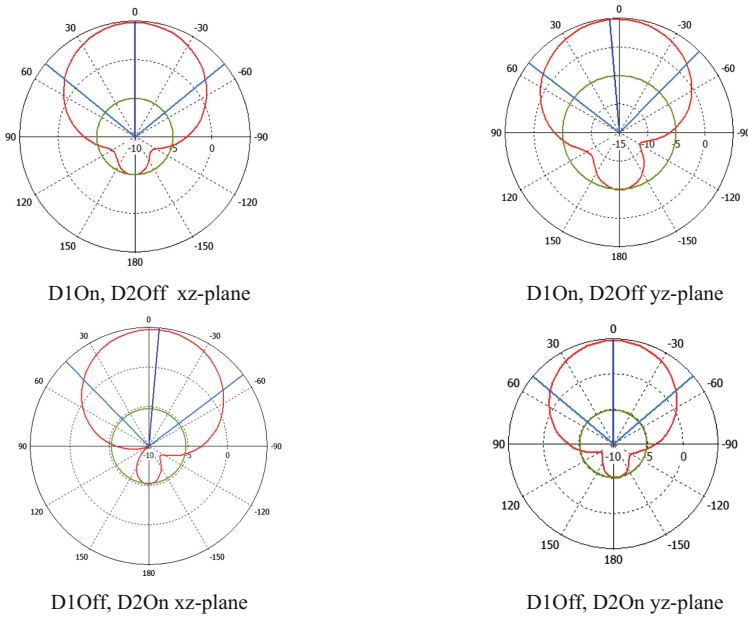

D1On, D2Off xz-plane

D1On, D2Off yz-plane

D1Off, D2On xz-plane

D1Off, D2On yz-plane

Fig. 3. Simulated results for radiation pattern for microstrip antenna

From Fig. 4, the axial ratio can be also observed. At resonance (3.6 GHz), a value of less than 2 dB axial ratio resulted with the difference between the cross-polarization component and the co-polarization component also less than 2 dB. In simulated results, circular polarization is observed at each state of switching and in the xz-plane and yz-plane. However, the results obtained show circular polarization at broadside and at the most important direction in both xz-plane and yz-plane.

Figure 5 shows the captured view of an animated field explaining the sense of rotation of circular polarization for the antenna. It shows that the filed distribution of the proposed antenna is rotating in the left-hand circular polarization in the D1Off, D2On state, whereas the field is rotating in the right-hand circular polarization in the D1on, D2off state.
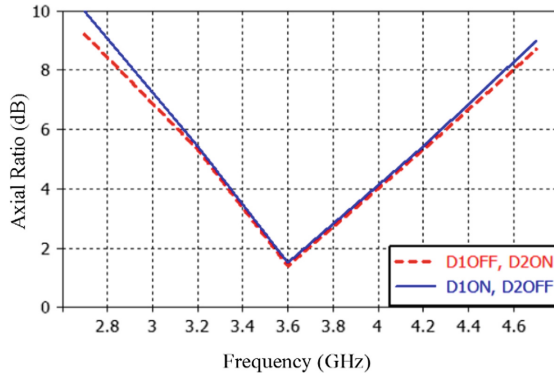
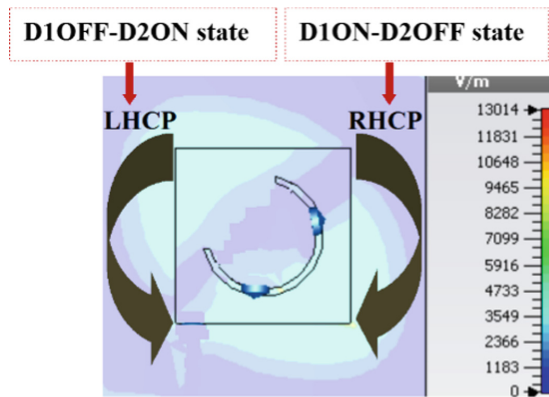**Fig. 4.** Simulated axial ratio for the antenna.

Fig. 5. Captured view of animated field shows the sense of rotation of CP for the antenna.

Figure 6 shows the simulation results for the maximum realized gain of the proposed antenna. The maximum value for simulated gain is 4.8 dB for both switching states for the diodes at the resonance frequency.

4   Comparison with Some Other Existing Structures

Table 2 compares the proposed polarization-reconfigurable antenna with other antennas with similar configurations and performance. It is noticeable that the proposed antenna is better than others with respect to size, number of switches and also the polarization states obtained compared with the design complexity.
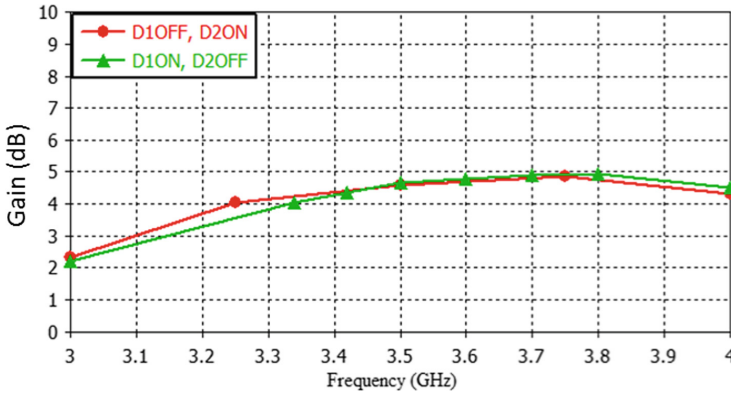
Fig. 6. Simulation results for the realized gain of the proposed antenna

Table 2. Comparison between the proposed structure with some other existing structures.

Ref.	Antenna size (mm^3)	f$_0$ (GHz)	No. of switches	Design complexity	Achieved polarization
[9]	70 × 70 × 1.6	1.5	4	Simple	LP-RHCP-LHCP
[10]	140 × 80 × 10	2.4	2	Simple	RHCP-LHCP
[11]	80 × 80 × 3.2	2.4	6	Very complex	VP-HP-SP-RHCP-LHCP
[13]	70 × 70 × 10.8	2.4	2	Simple	RHCP-LHCP
[14]	100 × 100 × 3.2	1.5	2	Consists of two layers	HP-VP-RHCP
[15]	67.5 × 39.3 × 1.52	2.4	2	Simple	LP-CP
This work	30 × 30 × 3.2	3.6	2	Simple	RHCP-LHCP

5   Conclusions

A proposed design for a 5G circular polarization reconfigurable-microstrip antenna is presented in this paper. The antenna is reconfigurable for circular polarization to cover RHCP and LHCP under the control of PIN diode switches. The proposed design exhibits 11%–8% effective bandwidth with maximum realized gain around 4.8 dB at 3.6 GHz. Only two switches are used for switching the mode of polarization. The antenna characteristics are kept the same at each polarization mode due to symmetry through switching. The antenna covers the 5G frequency band for potential use in stationary terminals of various wireless applications and it is suitable for WiMax applications and MIMO systems as well.

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